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(54) Title: RADIO CHANNEL QUALITY ESTIMATION

(57) Abstract

A method of and an apparatus for estimating the quality of service of a radio channel in a radio communications system. The bit error rate for each of a set of plural samples of a signal on a radio channel is estimated. The number of bit error valves in the set falling within each of a plurality of particular bit error rate ranges is determined. The determined distribution of the bit error rate values in the sampled set is then compared with predetermined reference bit error rate distributions which each represent a different channel service quality. The quality of the sampled signal is determined to be the quality of the reference distribution that the sampled signal bit error rate value distribution most closely matches.

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Radio Channel Quality Estimation

The present invention relates to a method of and apparatus for estimating the quality of service provided by a radio channel.

In many mobile radio communication systems, such as private mobile radio systems and cellular telephone systems, it is desirable to be able to estimate the quality of service provided by a radio channel. Such quality estimates can be used, for example, to drive cell or base station reselection processes to maintain radio channel quality, or to help decide when and if to hand a portable radio over from its present base station or cell to an adjoining base station or cell as the radio moves around. Typically a cell reselection or handover decision would be based on, *inter alia*, which of the present and potential new radio channels have the better quality. There is therefore a need for a reliable method of estimating the quality of radio channels.

A number of different parameters, such as the received signal strength, the signal to noise ratio, the carrier to interference ratio, or the bit error rate of the signal, can be used as an indication of the signal quality on a radio channel. For example, a high received signal strength implies a strong signal and thus could be equated to a "good" quality channel. One way of estimating radio channel service quality therefore is to consider the instantaneous value of one or more of the parameters typically used as an indication of the channel quality.

However, in a typical mobile radio communications environment, signal degradation and errors will occur in a very bursty manner due to the presence of Rayleigh fading in the communications channels. This can lead to

problems when using a single measurement to estimate the channel quality. It is therefore desirable to perform some form of filtering of the signal quality data to provide a more statistically stable result (and thus a more reliable estimate for the channel quality). This can help, for example, to prevent unnecessary "ping-pong" effects where a mobile radio bounces between a number of radio sites if the estimate is being used to drive cell reselection.

One way to do this is to take the average, i.e. arithmetic mean, of plural signal quality measurement samples. However, a problem with such averaging is that for it to be practically useable, i.e. able to respond quickly to real quality changes, it must be performed over a relatively small number of samples, which means that the averaging process remains susceptible to errors caused by abnormal samples, such as unusually high error bursts arising, for instance, from some form of external interference.

According to a first aspect of the present invention, there is provided a method of estimating the quality of service of a radio channel in a radio communications system, comprising:

determining the value of a parameter indicative of signal quality for each of a plurality of samples of a signal on the radio channel; and

estimating the radio channel service quality on the basis of the distribution of the values in a set of two or more of the determined parameter values.

According to a second aspect of the present invention, there is provided an apparatus for estimating the quality of service of a radio channel in a radio communication system, comprising:

means for determining the value of a parameter indicative of signal quality for each of a plurality of samples of a signal on the radio channel; and

means for estimating the radio channel service

quality on the basis of the distribution of the values in a set of two or more of the determined parameter values.

In the present invention, a set of values of a parameter indicative of signal quality is determined for a signal on the radio channel, and the channel service quality is estimated in accordance with the distribution of the values in the set.

The Applicants have found that the way that the values in a set of sampled values of a parameter indicative of radio signal quality are distributed or spread differs for different signal qualities, such that the distribution of the parameter values can be used as an indicator of and thus to estimate radio channel service quality. However, because the distribution of the parameter values is being used, the quality estimate is less susceptible to errors introduced by abnormal sample values. It is believed therefore that the present invention provides a more reliable method of estimating radio channel service quality in a mobile radio system.

Indeed the Applicants have found that it will in many cases provide a better estimate of radio channel service quality than, for example, merely averaging bit error rates and that in particular it is much less susceptible than averaging to quality estimation errors caused by abnormal samples with very high bit error rates.

The frequency and spacing of the samples for which the parameter value is determined can be selected as desired, e.g. to achieve the required number of samples in the time period allowed to produce the quality estimate and/or the number necessary to achieve a reliable estimate. Preferably, the samples are taken at spaced, preferably regular and preferably predetermined, time intervals, e.g. every second.

For example, to take into account the effects of

Rayleigh fading, the samples could be distributed in space across 100 to 200 radio carrier wavelengths. To achieve this at typical vehicle speeds at 400 MHz, it would therefore be convenient to take samples at 1 second intervals. For pedestrians in an indoor environment using very small "pico-cells", the sampling rate could, for example, be fixed at an interval corresponding to traversing about 20 wavelengths per sample at 3 mph. At 1800 MHz this would be 2.5 seconds. It would be possible to vary the sampling interval in direct proportion to the speed of the mobile radio unit, but this is not essential.

The form of the samples will depend on the parameter being measured, but could, for example, comprise a particular portion of the radio signal. In systems where the signal comprises discrete packets, timeslots or bursts,(such as in TETRA (TErrestrial Trunked RAdio)), each sample preferably comprises a single packet, timeslot or burst, if appropriate (e.g. when using bit error rates as the parameter indicative of signal quality). In the TETRA system, for example, samples are preferably taken every 18th frame, as that frame is idle and not necessarily used for traffic or useful information.

The number of sampled parameter values of the radio signal in the set of which the distribution is to be considered can also be selected as desired and would normally be predetermined. There should be sufficient values for their distribution to provide a sufficiently reliable estimate, but the greater the number of values, the longer the quality estimation process takes. A set of ten or more samples is preferred, to ensure adequate statistical reliability. The upper limit on the number of samples in the set is determined by the time it takes to gather the samples. For a reasonable response, a collection time of 60 seconds or less is preferred.

The parameter indicative of signal quality can be

any such parameter known in the art, such as the received signal strength, the signal to noise ratio, or the carrier to interference ratio. Preferably the signal quality parameter is a single variable, such as the bit error rate alone (rather than in combination with another variable).

In a particularly preferred embodiment the parameter is the bit error rate (BER). This has been found to be particularly suitable, since it corresponds more closely to the user's perception of signal quality.

The bit error rate for each sample can be determined in any suitable way known in the art. For example, the sample could be taken from a portion of the signal comprising a known sequence of bits (e.g. a so-called 'training sequence') and the sampled sequence compared with the known sequence to determine the bit error rate. Alternatively, the number of errors in a section of the signal could be assessed by examining the forward error correction (FEC) information which is inserted into the signal for protection of channel errors. However, this is not as effective as examining a known sequence, such as a training sequence, as an error in the FEC part of the signal may give a misleading result. In a TETRA system, the 'frequency correction burst' and 'synchronisation channel' may also be used to assess the bit error rate.

In another particularly preferred embodiment, the parameter indicative of signal quality is the variation of a set of two or more determined values for a given parameter for a signal on the radio channel. Thus the present invention preferably further comprises steps of or means for determining the value of a particular parameter for each of a plurality of samples of a modulated signal on the radio channel; and determining the variation of a set of two or more of the determined parameter values. The determined variation value or measurement would then be used as one sampled value of

the parameter indicative of signal quality, such that plural such variation values would be used to form a set whose distribution could then be determined to provide an estimate of service quality.

The Applicants have recognised that the variation of a set of determined values of a particular parameter for a radio signal gives an indication of the consistency of the signal over the set of samples, and can therefore be used as an indicator of signal quality. The variation will depend upon both signal fading and any high-energy interference which is increasing the received signal energy, and thus is sensitive to the effects of interference (e.g. co-channel and adjacent channel interference and narrow band jamming), in addition to additive white Gaussian noise. Furthermore, determining the variation does not involve the comparison of known signal sequences, and thus does not require any prior knowledge of what has been transmitted nor need any synchronisation between transmitter and receiver.

Thus according to a third aspect of the present invention, there is provided a method of estimating the quality of service of a radio channel in a radio communications system, comprising:

determining the instantaneous value of a particular parameter for each of a plurality of samples of a modulated signal on the radio channel;

determining the variation of a set of two or more of the determined parameter values;

determining the variation of at least one further set of two or more of the determined parameter values; and

estimating the radio channel service quality on the basis of the distribution of the values in a set of two or more of the determined variation values.

According to a fourth aspect of the present invention, there is provided an apparatus for estimating

the quality of service of a radio channel in a radio communication system, comprising:

means for determining the instantaneous value of a particular parameter for each of a plurality of samples of a modulated signal on the radio channel;

means for determining, for each of two or more sets of two or more of the determined parameter values, the variation of the determined parameter values in the set; and

means for estimating the radio channel service quality on the basis of the distribution of the values in a set of two or more of the determined variation values.

The particular parameter, the instantaneous values and variation of which are to be determined, can be selected as desired and could comprise a parameter normally used to estimate signal quality such as signal strength. It is preferably predetermined.

In a particularly preferred embodiment the selected particular parameter is one that would, in an ideal signal, be substantially identical for each sample of the signal, as then any variation in the parameter value will be due substantially to signal degradation or distortion, i.e. quality loss.

The Applicants have recognised that in many radio communication systems, the modulation technique used imparts to the carrier wave characteristics which at the instant of modulation are common to every sample or a particular set of samples of the signal on the radio channel. For example, in analogue systems, the radio signal may be modulated to initially have one or more constant parameters. In FM (frequency modulation) the amplitude of each sample of the signal is set to be the same and in AM (amplitude modulation) the relative phase of the signal is set to be the same.

In digital modulation, samples, and in particular symbols (i.e. the discrete individual states to which

the modulated signal is constrained at periodic intervals, as is known in the art), of the signal are also initially modulated to have one or more identical, common characteristics or parameters. For example, each symbol may be modulated to have the same initial amplitude relative to the carrier wave. Alternatively or additionally each symbol may be initially modulated to have one of a set of predetermined values of a particular parameter or parameters, which value or values are then varied relative to each other for one or more symbols in a predetermined manner by the modulation, such that removal of the known modulation induced differences would leave each symbol with the same value for that particular parameter or parameters. An example of this could be the phase of each symbol relative to the carrier wave, which could be identical when the symbols are demodulated or mapped to a common phase quadrant so as to remove modulation-induced phase differences.

Thus the particular parameter, the variation of which is to be considered, could, for example, comprise the amplitude of each sample, or a phase measurement for each sample, relative to the carrier wave.

In an ideal signal these common characteristics or parameters would remain unchanged (and thus identical) during transmission. However, in practice, these common characteristics are distorted or changed by different amounts during transmission. Thus by looking at the variation of the nominally common characteristics (e.g. sampled signal amplitude) over a set of samples of the received signal, a particularly good indication of the distortion induced in the transmitted signal, and thus the signal quality, can be obtained, and using only a relative small number of samples.

The samples of which the particular parameter values are to be determined can be selected (e.g. as regards their spacing in time) as desired, as can the

number of determined particular parameter values to be used in the set of which the variation is to be considered. Preferably, the set comprises a predetermined number of parameter values, and preferably at least sufficient values to average out variations caused by Gaussian noise, and, where appropriate, most preferably sufficient values to average out Rayleigh fading. The spacing and timing of the samples, and the number in a set, should be such as to provide a practically useful and statistically reliable result (e.g. to avoid sampling over too long a period for a given set which might lead to errors induced by users deliberately changing the power of their signals), as will be appreciated by those skilled in the art.

In a particular preferred embodiment the samples, the particular parameter values of which are to be determined, are selected to ensure that the parameter value being considered would be substantially identical for each sample in an ideal signal. Thus where a digitally modulated signal is being analysed, the samples preferably comprise symbols, and most preferably immediately successive symbols, of the digitally modulated signal.

The particular parameter value for each sample can be determined in any suitable manner known in the art. For example, the sampled symbols of a digitally modulated phase-shift keyed signal can be demodulated (or differentially demodulated, if differential phase-shift keying is used, such as would be the case in the TETRA system) or mapped to give notionally common characteristics (e.g. phase values) i.e. to remove any modulation induced parameter, e.g. phase, differences, and the variation of one or more of the parameters, such as amplitude or phase of the so mapped or demodulated signals then analysed. This mapping could be done by, e.g. taking the modulus of the real and imaging parts of each symbol, and/or by changing the determined

instantaneous parameter value in a predetermined manner based on the determined instantaneous value.

The variation of the set of determined particular parameter values can be determined in any suitable manner. For example, the extent of deviation of the values from a mean, modal or middle value, the range of the values, the difference between two selected values (e.g. the highest and lowest), or the standard deviation of the set of values could be used to indicate and represent the variation.

In one preferred embodiment, the variation is determined by calculating the variance of the set of the determined particular parameter values. This is a particularly suitable way of determining the variation of a set of parameter values. Thus the apparatus of the present invention preferably comprises means for calculating the variance of the set of the determined particular parameter values. The variance of the set of determined parameter values can be calculated using known statistical techniques.

In another preferred embodiment, the variation of the set of sampled values is determined by considering the error of each value from its expected value and then considering the errors of a set of sampled values. For example, by statistical analysis, such as taking the mean or modal error value, or considering the variation (e.g. variance or standard deviation) of the error values, a measure of the variation of the parameter values can be obtained.

The error value for each sample can be derived as desired. It is preferably the difference between the expected instantaneous parameter value (e.g. amplitude or phase) (which value would normally be predetermined by the modulation technique being used) and the observed determined value of that parameter for that sample. In a digitally modulated signal, the samples should be symbols of the signal, and thus the error value is

preferably the difference between the expected instantaneous amplitude or phase of a symbol of that type and the observed amplitude or phase value, respectively, for the symbol.

In a particularly preferred embodiment where the quality of a digitally modulated radio channel is to be estimated, the present invention preferably comprises steps of or means for measuring the amplitude and/or phase of each of a plurality of symbols in a digitally modulated signal on the radio channel; and determining the variation of a set of two or more of the measured amplitude and/or phase values.

This embodiment of the present invention preferably further comprises steps of or means for removing any modulation induced phase and/or amplitude differences between the symbols in the set to provide a modified set of symbols having nominally identical amplitudes and phases, and then measuring the amplitude and/or phase of each symbol in the modified set of symbols and using these measurements for the variation determination.

The determined variation measurements can be used directly, to form a set the distribution of which is then considered to estimate service quality, or they can first be converted into a corresponding bit error rate measurement, if desired. The latter can be achieved, for example, by relating the variation results to equivalent bit error rates (e.g. experimentally or by using a simulation), and determining therefrom a relationship, curve-fit or look-up table from which the corresponding bit error rates can in future be derived.

The distribution of parameter values indicative of signal quality in the sampled set can be assessed as desired. For example, the way that the values in the set are spread or dispersed across a range of the parameter values can be considered. In a particularly preferred embodiment, the distribution is assessed by determining the number of determined values in the set

falling within each of a plurality of particular ranges of the parameter value. This sorting of the determined values in the set into plural ranges is a particularly convenient way of representing the distribution for subsequent analysis and use in the estimation process. It effectively estimates the probability density function of the parameter values in the set (i.e. the probability of the parameter having a particular value), since the number of values in a range, divided by the total number of values in the set, is the probability of the parameter value falling within that range.

The number and size of the ranges of parameter values to be used can be selected as desired. The ranges would normally be predetermined. Each range could, for example, be defined by the value of the parameter being greater than or less than a particular value, or being between two particular values. More ranges are more accurate, but increase any calculation complexity. Three has been found to be a suitable number to give a useful estimate of the service quality. These ranges could, for example, be as follows: Range 1: $<$ 0.7% BER; Range 2: 0.7% to $<$ 5.7% BER; and Range 3: $\geq$ 5.7% BER. In this example, range 2 spans the bit error rates thought to be marginal for communication purposes, range 1 represents a good signal, and range 3 an unusable signal.

It should be noted that the above preferred minimum of 10 samples in the set, the distribution of which is to be assessed, is particularly suitable for sorting into three ranges. If additional ranges over three are to be used, the number of samples in each set is preferably increased above the preferred minimum of 10 (in proportion to the number of ranges) to make better use of the additional ranges.

The channel service quality is preferably estimated by comparing the distribution of values in the sampled set with one or more predetermined reference

distributions of values of the parameter, and making the estimation on the basis of that comparison. Preferably the comparison is with plural, preferably three or more, predetermined distributions of parameter values, each corresponding to a particular, different channel service quality. The channel service quality of the sampled radio channel can then be determined to be that of the reference distribution which its sampled set distribution most closely matches. The predetermined reference comparison distributions can conveniently be stored in memory means in the radio channel quality estimation apparatus.

The number of predetermined distributions for comparison can be selected as desired. More comparison distributions increase the usefulness of the quality estimation, but are more susceptible to erroneous estimation, whereas fewer comparison distributions make the process less useful. Three comparison distributions, corresponding to "good", "neither" and "bad" channel service quality, have been found to provide a useful estimation function.

The reference distributions are preferably represented in a manner corresponding to the way in which the distribution of parameter values in the sampled set of values is to be assessed, as this makes the comparison process more straightforward.

Thus, in a particularly preferred embodiment, where the distribution of values for the sampled radio signal is assessed by determining the number of values in the set of sampled parameter values falling within particular value ranges, the comparison reference distributions each comprise a set of numbers representing the probability of the parameter value falling within the same particular value ranges for a signal of the quality that the reference distribution represents. Most preferably, where a predetermined number of sampled values is used for the or each set to

be analysed, the comparison distributions comprise the number of the values in a set of that predetermined number of values that should fall within each of the particular ranges for a signal of the quality that the reference distribution represents.

These arrangements make the comparison process particularly straightforward, since the closest comparison distribution can be found by comparing directly the numbers in the comparison distribution with the number of values in each range determined for the set of sampled values. The closest comparison distribution can be found, for example, by determining which comparison distribution has the minimum estimated mean square error with the sampled set value distribution.

This arrangement is thought to be a particularly convenient way of estimating the quality of service provided by a radio channel. Thus, according to a fifth aspect of the present invention, there is provided a method of estimating the quality of service of a radio channel in a radio communications system, comprising:

determining the value of a parameter indicative of signal quality for each of a plurality of samples of a signal on the radio channel;

determining the number of values, of a predetermined number of the determined parameter values, falling within each of a plurality of predetermined ranges of the parameter value;

comparing the set of determined numbers of values falling within each range with two or more predetermined sets of numbers of parameter values falling within each range, each predetermined set corresponding to a particular signal quality; and

estimating the quality of service to be the quality of service represented by the predetermined set that the set of determined numbers of values falling within each range most closely matches.

Thus, according to a sixth aspect of the present invention, there is provided an apparatus for estimating the quality of service of a radio channel in a radio communications system, comprising:

means for determining the value of a parameter indicative of signal quality for each of a plurality of samples of a signal on the radio channel;

means for determining the number of values, of a predetermined number of the determined parameter values, falling within each of a plurality of predetermined ranges of the parameter value;

means for storing two or more predetermined sets of numbers of parameter values falling within each range, each predetermined set corresponding to a particular signal quality;

means for comparing the set of determined numbers of values falling within each range with the predetermined sets of numbers of parameter values falling within each range; and

means for estimating the quality of service on the basis of the comparison.

The predetermined reference distributions can be determined as desired, e.g. by analysing the parameter value distribution in samples of actual radio signals. Alternatively, the radio signals could be simulated in known radio system simulation packages and the distributions determined from the simulation. Preferably these reference distributions are determined using a large number of samples, to make them statistically reliable. The distribution of values from the simulation or actual measurement may be used directly for the reference distributions, or the comparison distributions can be modified, e.g. in the light of practical experience, to, for example, take account of quantisation effects if a limited number of value ranges is to be used in the estimation process.

In a particularly preferred embodiment, the

estimation is further dependent on the speed of the mobile radio and thus the present invention further comprises a step of or means for determining the speed of a mobile radio. The Applicants have found that the velocity of a mobile radio can affect the results of a radio channel quality estimation process. This is because, *inter alia*, radio signal fades are determined by nodes in the signal, and thus the more rapidly a mobile radio is travelling the closer together any fades will be in time. Also, the faster a mobile is travelling, the more quickly it is likely to leave its present cell. Thus by modifying the estimation process to take account of the mobile's speed, it can be further optimised.

For example, the reference distributions used in the estimation process could be selected depending upon the mobile's speed, with there being different such distributions associated with different speeds of the mobile. For example, three sets of reference distributions could be stored in the mobile radio unit, corresponding to low, medium and high speed (e.g. < 3 km/h (no mobility, no handover expected), 3 to 30 km/h, 30 to 100 km/h, and 100 to 500 km/h). The mobile unit would then choose the appropriate set of reference distributions for comparison with the observed samples' distribution on the basis of its current speed.

Indeed, the idea of modifying a radio channel quality of service estimation process to take account of the speed of a mobile radio is thought to be advantageous in its own right and not just in the context of the present quality estimation process.

Thus according to a seventh aspect of the present invention, there is provided a method of estimating the quality of service of a radio channel for a mobile radio in a radio communications system, comprising:

determining the current speed of the mobile radio;

selecting in accordance with the determined speed

of the mobile radio one radio channel quality estimation algorithm from a group of predetermined radio channel quality estimation algorithms; and

estimating the radio channel quality using the selected algorithm.

According to an eighth aspect of the present invention, there is provided an apparatus for estimating the quality of service of a radio channel for a mobile radio in a radio communications system, comprising:

means for determining the current speed of the mobile radio;

means for storing a number of predetermined radio channel quality estimation algorithms, each algorithm being associated with a particular mobile radio speed or speeds;

means for selecting one of the stored predetermined algorithms on the basis of the determined speed; and

means for estimating the radio channel quality using the selected algorithm.

The quality of service estimation method and apparatus of the present invention can be used whenever quality of service estimates would normally be used, for example in handover and cell or base station re-selection processes. It could be operated repeatedly at selected, e.g. regular intervals, to provide a continually updated estimate of the service quality on the channel, or on demand (e.g. when requested by a base-station). When operated repeatedly, the channel quality can be estimated each time without duplication of the parameter values in the sets of which the distribution is being considered, e.g. when ten values are used, every ten new samples. Alternatively, it can be estimated using values used in a previous estimation together with new values, e.g. after each new sample (using the necessary number of immediately preceding values as the remaining values) or every two or three new samples, etc.

The methods in accordance with the present invention may be implemented at least partially using software e.g. computer programs. It will thus be seen that when viewed from a further aspect the present invention provides computer software specifically adapted to carry out the methods hereinabove described when installed on data processing means. The invention also extends to a computer software carrier comprising such software which when used to operate a radio system comprising a digital computer causes in conjunction with said computer said system to carry out the steps of the method of the present invention. Such a computer software carrier could be a physical storage medium such as a ROM chip, CD ROM or disk, or could be a signal such as an electronic signal over wires, an optical signal or a radio signal such as to a satellite or the like.

It will further be appreciated that not all steps of the method of the invention need be carried out by computer software and thus from a further broad aspect the present invention provides computer software and such software installed on a computer software carrier for carrying out at least one of the steps of the methods set out hereinabove.

A number of preferred embodiments of the present invention will now be described by way of example only and with reference to the accompanying drawings, in which:

Figure 1 shows a probability density function of burst errors for a TETRA signal having a 0.7% bit error rate;

Figure 2 shows a probability density function of burst errors for a TETRA signal having a 2% bit error rate;

Figure 3 shows a probability density function of burst errors for a TETRA signal having a 6% bit error rate;

Figure 4 shows an apparatus for determining the

variation of a set of sampled parameter values;

Figure 5 shows a modulated π/4 differential quaternary phase-shift keying modulated TETRA signal;

Figure 6 shows the demodulated form of the signal shown in Figure 5;

Figure 7 shows the demodulated constellation points of Figure 6 mapped to the first quadrant of the graph; and

Figure 8 shows the probability density function of the points on the graph in Figure 7; and

Figure 9 is a graph of signal power against time for an exemplary radio signal subjected to a Rayleigh fading envelope.

The following embodiment of the present invention illustrates its use in a TETRA system using the bit error rate alone as the parameter indicative of signal quality (although as noted above, other parameters can be used instead), and compares it to channel service quality estimation using the average bit error rate.

Firstly, a number of bit error rate probability density functions for known signal strengths and qualities were determined to act as reference parameter value distributions.

This was done by simulating TETRA signals of known quality using the COSSAP TETRA system simulation package (COSSAP is a digital simulation software package licensed by Synopsis Inc., 700 East Middlefield Road, Mountain View, CA 94043, U.S.A.) and analysing the probability density function of the burst errors in those signals. Of course, other system simulation tools could be used, if desired. The simulation was configured to provide the bit error rates (BERs) of the bursts (i.e. packets) in the signals.

A number of simulations were performed using the standard fixed point library modelling the TETRA radio subsystem. The number of errors per burst for 20,000 bursts were collected and dumped to a file. Individual

files were created for a signals over range of carrier to interference, C/I, values corresponding to average BERs of 12%, 6%, 2%, 0.7% and 0.4%.

Using the Matlab numerical analysis package (again other packages could be used, if desired), the data from the 6%, 2% and 0.7% trials were used to generate a probability density function (PDF) for each of the trials. These trials were chosen because 2% BER represents a quality threshold in TETRA. To more accurately simulate the process that will occur in TETRA when neighbour cell monitoring is done during a full duplex call, only the burst in the 18th frame was considered.

The measured BERs from the simulation were grouped into three ranges or bins as shown in Table 1 below.

Table 1. Classification of Bins for the BER PDF analysis

Bin1	Bin2	Bin3
<0.7%	>=0.7%-<5.7%	>=5.7%

The number of value ranges was restricted to three because it was felt that satisfactory performance could be achieved with three thereby reducing the algorithmic complexity. More ranges could be used, if desired.

Probability density functions using these BER ranges were estimated for the 6% (representing a bad channel), 2% and 0.7% (representing a good channel) overall BER data. These PDFs are shown in Figure 1, Figure 2 and Figure 3.

From the form of the PDFs it is clear that the three different channel states exhibit bit error rate distributions or probability density functions that are different. The distribution of the bit error rate values can therefore be used as a channel quality "fingerprint" for comparison with a sampled channel.

Using the above PDFs, the number of sampled BER values of a signal of that quality from a set of ten sampled values expected to fall within the BER ranges (bins) shown in Table 1 were estimated to give reference bit error rate value distributions for the three channel quality types "good", "neither" and "bad". These reference distributions are to be used as comparisons for the channel quality estimation. (A set of ten sampled values was considered, because that was how many samples of the actual signal being analysed were to be used in the estimation process, but clearly other numbers of values could be considered.)

Table 2 shows the estimated value distributions:

Table 2. Coefficients for Channel "Fingerprint"

	BIN3	BIN2	BIN1
"Good"	0	1.0	9.0
"Neither"	1.5	1.5	7.0
"Bad"	2.5	1.5	5.0

The numbers of values differ slightly from the values that would be derived directly from the determined PDFs, because it was found that by varying slightly the number of values obtained from the PDF estimate for the channel quality a better overall result could be obtained. The amount to vary the number of values by can be determined experimentally by seeing which distributions of values work best in practice. (It is believed that the best set of numbers of values may not correspond directly to PDFs estimated from the simulations because of the effects of quantisation noise when using only three ranges with ten samples per quality estimate. These factors are presumed to add a slight weighting to the numbers of values in each range

that may be difficult to assess from a theoretical analysis.)

The value distributions or channel quality "fingerprints" in Table 2 may be used to estimate which of the 3 quality states a given radio channel is in, by comparing them with the distribution of a set of parameter values sampled from a radio signal on the radio channel.

It should be noted that the simulations were conducted using a fading rate corresponding to 50 kph at 400 MHz. This means that these derived comparison distributions or "fingerprints" are optimised for the 50 kph case. By repeating the simulations using fading rates corresponding to other speeds at 400 MHz, comparison distributions optimised for those other speeds can be derived. This is because the distributions will vary depending on the mobile unit's speed. At high speed Doppler shifts will contribute to the error mechanism, but errors due to fades will be short in duration (not affecting many bits in a burst), but frequent in occurrence. At low speed, fades will be of long duration, blanking out long sequences of bits, and causing problems for FEC mechanisms.

In the present embodiment the bit error rate of the packets (or bursts) in every 18th frame of a TETRA signal on a radio channel was determined and the distribution of a set of ten bit error rate values sampled from that single channel compared with the reference bit error rate value distributions of Table 2. The distribution of the bit error rate values of the ten samples was determined by sorting them into the three ranges described in Table 1, and this distribution was then compared with the three predetermined distributions described above by estimating the mean square error between it and each comparison reference distribution. The channel state represented by the comparison distribution that produced the minimum mean square error

was selected as the current channel quality state of the channel carrying the sampled signal.

Explicitly, the channel state is given by the value of j which minimises the following expression:

$$Min \left[\sum_{i=1}^{3} (x_i - y_{i,j})^2 \right] \quad j=1,2,3$$

Where x_i is the number of sampled BER values in the i^{th} bin or range, and $y_{i,j}$ are the predetermined number of values given in Table 2 where i is the bin or range number and j is the quality identifier (j=1: Good; j=2: Neither; j=3: Bad).

To continuously monitor the quality of a radio channel, this process can be repeatedly performed (e.g. in the present embodiment every 10s (which corresponds to 10 lots of the 18th frame), or by using a sliding process where the most recent 10 measurements are used).

As can be seen, the numerical processing only involves the squaring of nine numbers, and can easily be performed in the control processor of a mobile radio, or base station, as desired.

The performance of the present embodiment will now be assessed by comparing it with quality of service estimation using the arithmetic mean of the BER. As stated earlier, using the arithmetic mean is susceptible to errors caused by a single burst with an abnormally high bit error rate.

In this comparison, the estimated mean was used to quantify the channel states as good, bad or neither according to the following thresholds:

Table 3. Classification of Channel Quality for the BER Mean Method

"Good"	"Neither"	"Bad"
<0.7%	>=0.7% to <6%	>=6%

These thresholds are nominally the same as the ranges used for estimating the BER value distribution in the method of the present embodiment.

To assess the performance of the methods, two sets of COSSAP simulation data were used to simulate a good channel and a bad channel. Furthermore, in addition to using good and bad channels, two speeds (50 kph and 3 kph) were used to see what effect the speed of the mobile had on the estimation performance. As noted above, the reference distributions of the present embodiment was optimised for the 50 kph case but if the mobile has a knowledge of its speed then it could be modified to operate better at a speed of around 3 kph (for example, by using reference distributions obtained by repeating the simulations using a fading rate corresponding to 3 kph at 400 MHz).

To assess the accuracy of recognising a bad channel at 50 kph, a COSSAP simulation with an average BER of 12% using a typical urban radio channel at 50 kph was created. The number of errors per burst were counted and stored in a data file for analysing using a Matlab script. An average BER of about 12% should be definitely classified as a bad channel.

Table 4 shows the number of occasions for which the channel was classified as either good, bad or neither for each method. It can be seen that the present invention provides the most accurate reporting of channel states with no inaccurate estimates and a small number of "neithers". The mean estimation does not

perform quite so well reporting a larger number of "neithers" but no incorrect estimates.

Table 4. **Performance of Channel Estimation Methods at 50kph**

Method	"Good"	"Neither"	"Bad"
New	0	18	1980
Mean	0	123	1875

The COSSAP simulation was then repeated with an average BER of 12% and a typical urban channel model at 3 kph.

The results of the analysis of the two methods are shown in Table 5.

Table 5. **Performance of Channel Estimation Methods at 3 kph**

Method	"Good"	"Neither"	"Bad"
New	32	293	1673
Mean	12	335	1651

It is clear from these results that the present invention predicts the bad channel marginally better, but also reports more good channels. As stated earlier the distribution of the bit error rates is different at low speeds. If the vehicle speed can be estimated, then the set of comparison distributions can be optimised for different speeds.

Two COSSAP simulations that simulated a good radio channel (an average bit error rate of 0.4%) were then performed. The first simulation propagation channel used a typical urban propagation model at 50kph.

The performance of the two methods is shown in Table 6 below.

Table 6. **Performance of Channel Estimation Methods at 50kph**

Method	"Good"	"Neither"	"Bad"
New	1760	234	4
Mean	1598	400	0

The results show that the present invention predicted the good channel better, but also predicted a slightly higher number of Bad channels.

A COSSAP simulation that simulated a Good radio channel (BER of 0.4%) using a typical urban propagation channel at 3 kph was then performed.

The performance of the two methods is shown in Table 7 below:

Table 7. **Performance of Channel Estimation Methods at 3kph**

Method	"Good"	"Neither"	"Bad"
New	1877	121	0
Mean	1528	447	23

A brief review of these results show that the present invention performs better at low speeds under Good channel conditions.

The two methods were also compared for situations where a burst with a high average error rate (50%) is present. These high bursts of errors may occur due to external interference effects, or from the decoding of the wrong channel type.

To simulate this effect, the same simulation data from the COSSAP simulations was used, but one of the bursts was randomly substituted by an error burst with an error rate of 50%. The number and location of these bursts was controlled by a uniformly distributed random

number generator.

In all of the simulations, the probability of a sporadic bad burst was 0.01, i.e. on average 1 per 100 bursts would have an error rate of 50%. Whilst this is an extreme case, it illustrates the limiting performance of the two methods.

Table 8 shows the results of this simulation:

Table 8. Performance in the Presence of Sporadic Burst Errors

Method	BER	Velocity	Number "Good"	Number "Neither"	Number "Bad"
New	0.4%	50kph	1674	320	4
Mean	0.4%	50kph	1449	531	18
New	0.4%	3kph	1829	168	1
Mean	0.4%	3kph	1382	555	61
New	12%	50kph	0	15	1983
Mean	12%	50kph	0	111	1887
New	12%	3kph	27	288	1683
Mean	12%	3kph	11	310	1677

As can be seen the results of the present invention hardly change for the good channel conditions, but the mean method is quite susceptible to these error bursts with quite a dramatic increase in the number of Bad channels reported.

For the Bad channel under both low and high vehicle speeds, there is little noticeable change in performance from either method, as would be expected.

As can be seen from all of the above results, in a comparison with a method based on an estimation of the mean BER, the method of the present invention performs best for most conditions and extremely well under all

conditions.

Although the above examples have used the bit error rate as the parameter indicative of signal quality, as noted above, other parameters could be used, and one preferred such measure is the variation of a set of determined instantaneous values of a particular parameter for a signal on the radio channel.

Figure 4 shows an apparatus 1 suitable for assessing the variation in parameter values of a physical TETRA channel, and in particular of a $\pi/4$ differential quaternary phase-shift keying ($\pi/4$ DQPSK) modulated signal, such as might be present on that channel.

The plot of a sequence of TETRA $\pi/4$ DQPSK constellation points of an exemplary complex $\pi/4$ DQPSK signal is shown in Figure 5. A signal 2 such as this is input to a differential demodulator 3 of the apparatus 1, in which a sequence of such constellation points, x, which may be described by:

$$n = 1, \ldots\ldots, N$$
$$x = [x_1, x_2, x_3, \ldots\ldots, x_N]$$
$$x_n = i_n + j \cdot q_n$$

is differentially demodulated, as is known in the art, to produce a QPSK constellation like the one shown in Figure 6. The points in Figure 6 are the symbols of the signal (i.e. the parts of the signal which represent the data in the signal) and form the samples whose instantaneous parameter values (and their variation) are to be determined. The radius of the circle on which the constellation points lie (at the phases $+\pi/4$, $+3\pi/4$, $-\pi/4$, $-3\pi/4$) is proportional to the mean symbol energy μ_p.

The sequence 4 of demodulated constellation points or symbols, y, is given, as is known in the art, by:

$$y = [y_1, y_2, y_3, y_4, \ldots\ldots, y_N]$$
$$y_n = x_n.\text{Conjugate}(x_{n-1})$$
$$= (i_n.i_{n-1} + q_n.q_{n-1})+j.(q_n.i_{n-1} - i_n.q_{n-1})$$

Each demodulated constellation point comprises two orthogonal 'soft decisions' whose magnitude represents the instantaneous energy in the in-phase and quadrature-phase components of the signal samples.

The magnitudes of the instantaneous energies of the in-phase and quadrature-phase components of each demodulated constellation point in the sequence 4 of demodulated constellation points is then determined (this effectively maps the demodulated constellation points to the first quadrant to give a graph as shown in Figure 7) to generate the IQ scalar energy or symbol energy sequence, p:

$$p = [p_1, p_2, p_3, p_4, \ldots\ldots, p_{2N}]$$
$$p_{2n-1} = |\text{Re}\{y_n\}|$$
$$p_{2n} = |\text{Im}\{y_n\}|$$

The variance σ^2 of a set of the values in the scalar amplitude sequence can then be determined using standard statistical analysis:

$$\begin{aligned}\sigma^2 &= E[(p-\mu)^2]\\ &= E[p^2] - 2E[p.\mu]+E[\mu^2]\\ &= E[p^2] - 2\mu E[p]+\mu^2\\ &= E[p^2] - 2\mu^2 + \mu^2\\ &= E[p^2] - \mu^2\\ E[p^2] &= \Sigma(p_n^2/N)\\ \mu &= \Sigma(p_n/N)\end{aligned}$$

where μ is the mean symbol energy value of the number N of values in the set being used, and $E[a] = \Sigma(a_n/N)$.

A parameter indication of signal quality is given

by the variance:

$$\sigma^2 = \Sigma(p_n^2/N) - (\Sigma(p_n/N))$$

A low value of σ^2 indicates a good signal quality. Any additional in-band channel energy will increase σ^2, indicating a signal quality degradation. The signal quality indication therefore responds to co-channel interference, adjacent channel interference, and narrow band jamming in addition to additive white Gaussian noise.

Figure 8 shows an exemplary probability density function for a symbol scalar amplitude sequence derived as described above.

Although in the above example the variance of the energy sequence was determined, as can be seen from Figure 7, there are four common characteristics or parameters of the mapped symbols. These are:

- The distance of the mapped symbol from the origin
- The real part of the mapped symbol
- The imaginary part of the mapped symbol
- The phase of the angle subtended by the complex vector and the real axis.

The variation of any or all of these parameters could be considered, if desired.

The above example uses the variance of the set of parameter values as an indicator of signal quality. Other metrics indicative of the sampled values' variation can be used. One preferred such metric is to divide the mean of the set of values, e.g. symbol energy μ_p, by the standard deviation of the set, σ. This gives a metric which is proportional to the mean symbol energy (Es) and inversely proportional to both the background noise (N_0) and the interference (C_I) levels, which will each serve to increase the standard deviation

of the energy distribution:

$$\begin{aligned} Q &= \mu_p/\sigma_p \\ &\propto Es/(N_0 + C_I) \end{aligned}$$

This is a good metric upon which to base estimates of service quality and/or bit error rate (e.g. by means of curve fitting or the use of lookup tables from simulation or actual situation analyses).

In this embodiment the inverse square metric, Q_{IND} is preferably used as the quality of service indicator:

$$\begin{aligned} Q_{IND} &= 1/Q^2 \\ &= \sigma_p^2/\mu_p^2 \\ &= (E[p^2]/E[p]^2)-1 \end{aligned}$$

as this makes computation easier. The value Q_{IND} may be readily calculated and gets smaller as the quality of service improves.

By evaluating the metric Q_{IND} on the sequence p as described above, an efficient method for estimating the service quality of a TETRA signal is obtained.

In the above embodiment the mean symbol energy, μ_p, is preferably substantially constant throughout the set of symbols, as then any variation will be due to signal distortion. This has important implications when considering a practical radio communications system which may be subjected to a Rayleigh fading envelope, as shown for example, in Figure 9.

For example, the number of successive symbols N, over which σ^2 is evaluated should be less than T_Q/T_S (where T_Q is the period over which the mean signal amplitude μ_p is substantially constant and T_S is the symbol period), since over this set of symbols the mean symbol amplitude remains substantially constant.

If σ^2 is evaluated over an over an extended period T_V, by taking one long symbol sequence of length (T_V/T_S)

then the value μ_p is no longer constant, and its variation would contribute to the signal quality metric σ^2 and make it less reliable.

The time T_U over which to evaluate the metric σ^2 can be selected as desired with these factors in mind. In a TETRA system, which is specified up to speeds of 200 kph, for example, Q_{INP} could be evaluated over N=16 symbols, since at this speed the fading envelope is roughly constant over such a period.

In an embodiment where the variation of a set of parameter values is being used as the parameter indicative of signal quality, variation values for successive sets of parameters would be determined as above, and then the distribution of a set of plural variation values used to estimate the radio channel service quality.

The present invention can be implemented in a mobile radio system as desired. It could, for example, be used by the mobile radio unit itself or a base-station of the system. It can be implemented in hardware or software, as will be appreciated by those skilled in the art.

The quality of service estimate provided by the present invention can be used wherever such estimates are normally used, such as to aid handover and cell-reselection decisions.

Although the present embodiment has been described with specific reference to the TETRA radio system, it is equally applicable to other radio communication systems, such as other private mobile radio systems, or cellular telephone systems.

Claims:

1. A method of estimating the quality of service of a radio channel in a radio communications system, comprising:

determining the value of a parameter indicative of signal quality for each of a plurality of samples of a signal on the radio channel; and

estimating the radio channel service quality on the basis of the distribution of the values in a set of two or more of the determined parameter values.

2. A method as claimed in claim 1, wherein the parameter indicative of signal quality is the estimated bit error rate of the signal sample.

3. A method as claimed in claim 1 or 2, comprising:

determining the value of a particular parameter for each of a plurality of samples of a modulated signal on the radio channel;

determining the variation of a set of two or more of the determined parameter values; and

using the determined variation as one sampled value of the parameter indicative of signal quality.

4. A method of estimating the quality of service of a radio channel in a radio communications system, comprising:

determining the value of a particular parameter for each of a plurality of samples of a modulated signal on the radio channel;

determining the variation of a set of two or more of the determined parameter values;

determining the variation of at least one further set of two or more of the determined parameter values; and

estimating the radio channel service quality on the basis of the distribution of the values in a set of two or more of the determined variation values.

5. A method as claimed in claim 3, or 4, comprising converting the determined variation values into corresponding bit error rate estimates, and using the distribution of a set of two or more of the corresponding bit error rate estimates to estimate service quality.

6. A method as claimed in any one of the preceding claims, comprising assessing the distribution of parameter values indicative of signal quality in the sampled set by estimating the probability density function of the parameter values in the set.

7. A method as claimed in any one of the preceding claims, comprising assessing the distribution of parameter values indicative of signal quality in the sampled set by determining the number of values in the set falling within each of a plurality of particular ranges of the parameter value.

8. A method as claimed in any one of the preceding claims, comprising estimating channel service quality by comparing the distribution of values in the sampled set with one or more predetermined reference distributions of values of the parameter, each reference distribution representing a particular channel service quality, and making the estimation on the basis of that comparison.

9. A method as claimed in any one of the preceding claims, comprising estimating channel service quality by comparing the distribution of values in the sampled set with two or more predetermined reference distributions of values of the parameter, each reference distribution

representing a particular, different channel service quality, and estimating the channel service quality to be the quality of service represented by the predetermined reference distribution that the distribution of values in the sampled set most closely matches.

10. A method as claimed in claim 8 or 9, comprising assessing the distribution of values for the sampled radio signal by determining the number of values in the set of sampled parameter values falling within particular value ranges, and wherein the comparison reference distributions each comprise a set of numbers representing the probability of the parameter value falling within the same particular value ranges for a signal of the quality that the reference distribution represents.

11. A method of estimating the quality of service of a radio channel in a radio communications system, comprising:

determining the value of a parameter indicative of signal quality for each of a plurality of samples of a signal on the radio channel;

determining the number of values, of a predetermined number of the determined parameter values, falling within each of a plurality of predetermined ranges of the parameter value;

comparing the set of determined numbers of values falling within each range with two or more predetermined sets of numbers of parameter values falling within each range, each predetermined set corresponding to a particular signal quality; and

estimating the quality of service to be the quality of service represented by the predetermined set that the set of determined numbers of values falling within each range most closely matches.

12. A method as claimed in any one of the preceding claims, further comprising determining the speed of the mobile radio receiving the signal on the radio channel and wherein the service quality estimate is also based on the determined speed of the mobile radio unit.

13. A method of estimating the quality of service of a radio channel available to a mobile radio in a radio communications system, comprising:

determining the current speed of the mobile radio;

selecting in accordance with the determined speed of the mobile radio one radio channel quality estimation algorithm from a group of predetermined radio channel quality estimation algorithms; and

estimating the radio channel quality using the selected algorithm.

14. An apparatus for estimating the quality of service of a radio channel in a radio communication system, comprising:

means for determining the value of a parameter indicative of signal quality for each of a plurality of samples of a signal on the radio channel; and

means for estimating the radio channel service quality on the basis of the distribution of the values in a set of two or more of the determined parameter values.

15. An apparatus as claimed in claim 14, wherein the parameter indicative of signal quality is the estimated bit error rate of the signal sample.

16. An apparatus as claimed in claim 14 or 15, comprising:

means for determining the value of a particular parameter for each of a plurality of samples of a

modulated signal on the radio channel;

means for determining the variation of a set of two or more of the determined parameter values; and

means for using the determined variation as one sampled value of the parameter indicative of signal quality.

17. An apparatus for estimating the quality of service of a radio channel in a radio communication system, comprising:

means for determining the value of a particular parameter for each of a plurality of samples of a modulated signal on the radio channel;

means for determining, for each of two or more sets of two or more of the determined parameter values, the variation of the determined parameter values in the set; and

means for estimating the radio channel service quality on the basis of the distribution of the values in a set of two or more of the determined variation values.

18. An apparatus as claimed in claim 16 or 17, comprising means for converting the determined variation values into corresponding bit error rate estimates, and means for using the distribution of a set of two or more of the corresponding bit error rate estimates to estimate service quality.

19. An apparatus as claimed in any one of claims 14 to 18, comprising means for estimating the probability density function of the parameter values in the set and means for assessing the distribution of parameter values indicative of signal quality in the sampled set using the estimated probability density function.

20. An apparatus as claimed in any one of claims 14 to

19, comprising means for determining the number of values in the parameter value set falling within each of a plurality of particular ranges of the parameter value, to thereby assess the distribution of parameter values indicative of signal quality in the sampled set.

21. An apparatus as claimed in any one of claims 14 to 20, comprising:

means for storing one or more predetermined reference distributions of values of the parameter, each reference distribution representing a particular channel service quality;

means for comparing the distribution of values in the sampled set with the predetermined reference distributions; and

means for estimating the channel service quality on the basis of that comparison.

22. An apparatus as claimed in any one of claims 14 to 21, comprising:

means for storing two or more predetermined reference distributions of values of the parameter, each reference distribution representing a particular, different channel service quality;

means for comparing the distribution of values in the sampled set with the predetermined reference distributions; and

means for estimating the channel service quality to be the quality of service represented by the predetermined reference distribution that the distribution of values in the sampled set most closely matches.

23. An apparatus as claimed in claim 21 or 22, comprising

means for determining the number of values in the set of sampled parameter values falling within

particular value ranges, whereby the distribution of values for the sampled radio signal may be assessed; and

wherein the comparison reference distributions each comprise a set of numbers representing the probability of the parameter value falling within said particular value ranges for a signal of the quality that the reference distribution represents.

24. An apparatus for estimating the quality of service of a radio channel in a radio communications system, comprising:

means for determining the value of a parameter indicative of signal quality for each of a plurality of samples of a signal on the radio channel;

means for determining the number of values, of a predetermined number of the determined parameter values, falling within each of a plurality of predetermined ranges of the parameter value;

means for storing two or more predetermined sets of numbers of parameter values falling within each range, each predetermined set corresponding to a particular signal quality;

means for comparing the set of determined numbers of values falling within each range with the predetermined sets of numbers of parameter values falling within each range; and

means for estimating the quality of service on the basis of the comparison.

25. An apparatus as claimed in any one of claims 14 to 24, further comprising:

means for determining the speed of the mobile radio receiving the signal on the radio channel; and

wherein the service quality estimate is also based on the determined speed of the mobile radio unit.

26. An apparatus for estimating the quality of service

of a radio channel available to a mobile radio in a radio communications system, comprising:

means for determining the current speed of the mobile radio;

means for storing a number of predetermined radio channel quality estimation algorithms, each algorithm being associated with a particular mobile radio speed or speeds;

means for selecting one of the stored predetermined algorithms on the basis of the determined speed; and

means for estimating the radio channel quality using the selected algorithm.

27. Computer software specifically adapted to carry out a method a claimed in any one of claims 1 to 13 when installed on data processing means.

28. A computer software carrier comprising software as claimed in claim 27.

FIG. 1

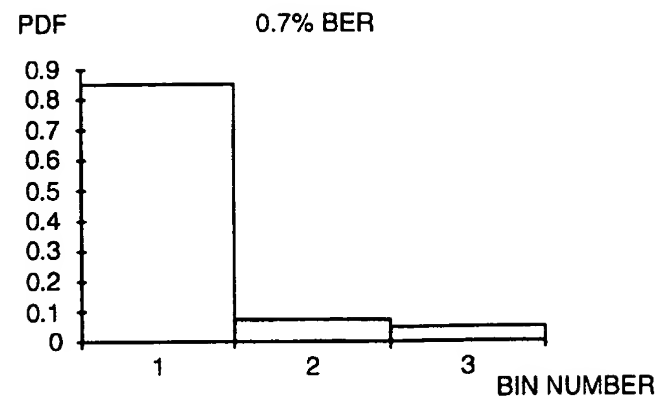


FIG. 2

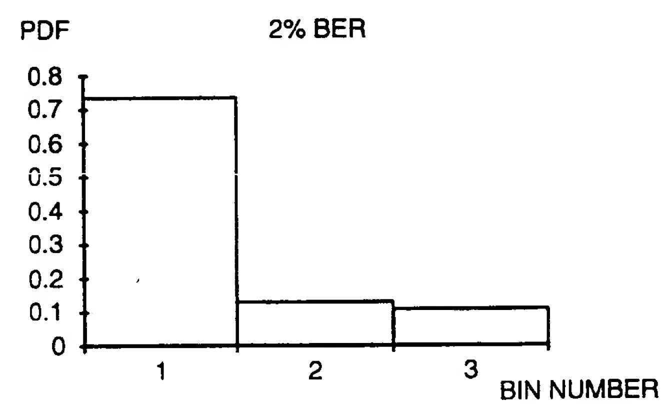
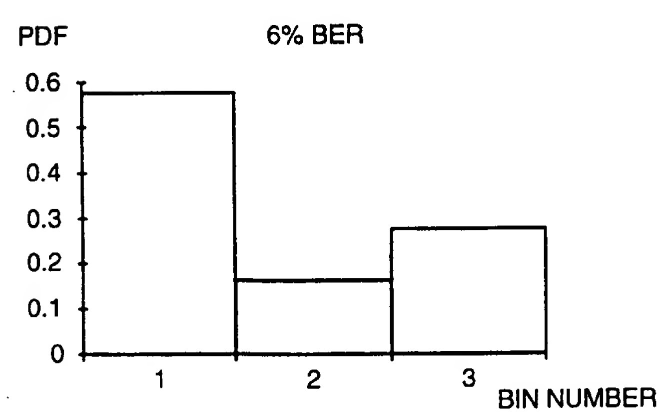


FIG. 3



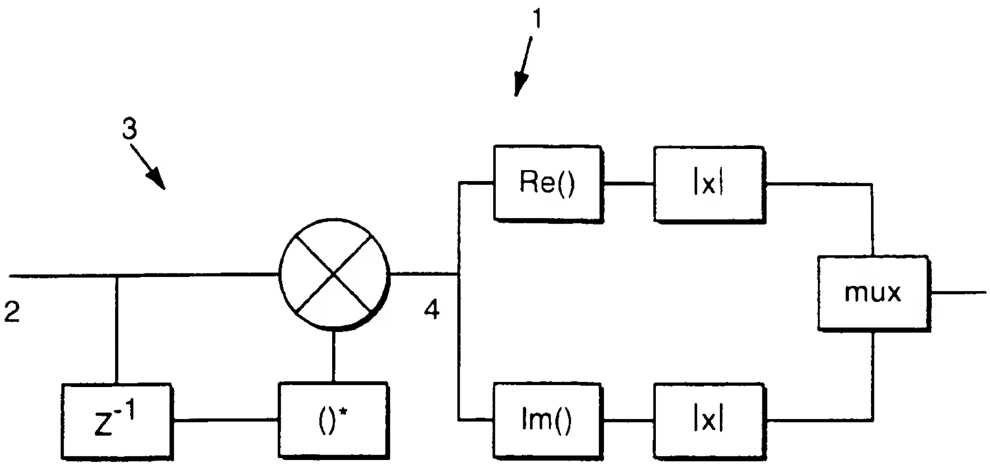
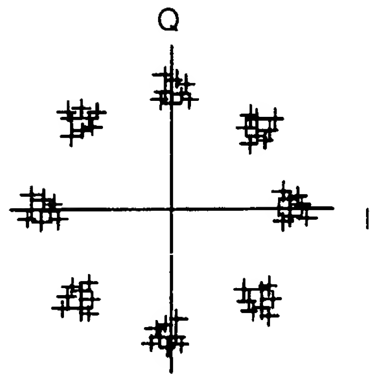
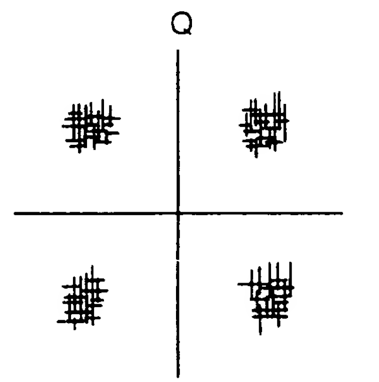


FIG. 4



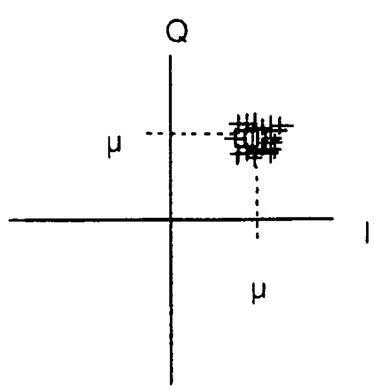
MODULATED PI/4DQPSK TETRA SIGNAL

FIG. 5



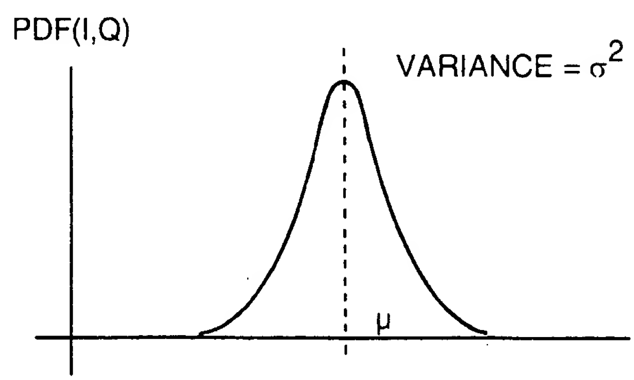
DEMODULATED PI/4DQPSK TETRA SIGNAL

FIG. 6



CONSTELLATION POINTS MAPPED TO 1st QUADRANT

FIG. 7



PDF OF CONSTELLATION POINTS

FIG. 8

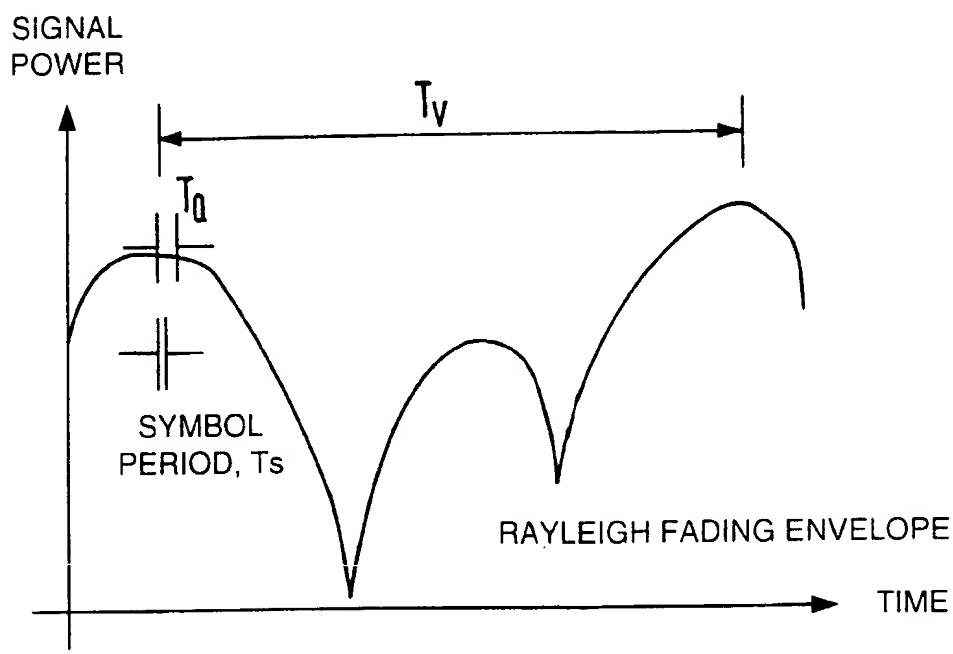

SIGNAL
POWER
T_V
T_Q
SYMBOL
PERIOD, Ts
RAYLEIGH FADING ENVELOPE
TIME

FIG. 9

INTERNATIONAL SEARCH REPORT

national Application No
PCT/GB 99/01530

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5 239 667 A (KANAI TOSHIHITO) 24 August 1993 (1993-08-24) abstract; claim 1	12,13, 25,26
A	US 5 214 687 A (KAENSAEKOSKI ANTTI ET AL) 25 May 1993 (1993-05-25) column 1, line 41 - column 2, line 57	1,4,11, 14,17,24
A	GB 2 307 375 A (BRITISH BROADCASTING CORP) 21 May 1997 (1997-05-21) claims 2,3	1,4,11, 14,17,24

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INTERNATIONAL SEARCH REPORT

national Application No
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A	US 5 214 687 A (KAENSAEKOSKI ANTTI ET AL) 25 May 1993 (1993-05-25) column 1, line 41 - column 2, line 57 ---	1,4,11, 14,17,24
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